Rice as a Crop for Salt-Affected Soil in Process of Reclamation

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Rice as a Crop for Salt-Affected Soil in Process of Reclamation [1]

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INTRODUCTION

The need to provide additional land for farming, in order to feed ever-increasing populations, has intensified the interest of economists, agriculturists, and government planning agencies in various types of unproductive land. Particularly in countries having arid or semi-arid climates, one opportunity for meeting future needs lies in reclamation of salt-affected soils. These are soils on which most crops cannot make normal growth owing to the presence of soluble salts in the soil solution (saline soils), the presence of exchangeable sodium on the surface of the soil particles (sodic soils), or both (saline-sodic soils). In extreme cases, there may be no plant growth at all.

The primary source of salt in soil is rock minerals from which salt is released by weathering. It is doubtful that weathering of any rock material could produce in place enough salt to make a soil unfit for agricultural use. However, rainwater percolating through the soil of one area can pick up salt and transport it to another area, and there salt may accumulate and become concentrated as a result of evaporation. This has been occurring for many centuries and is still occurring on flats, in dry lakebeds, and in enclosed basins. In some cases, the salinity of soils is explained by the fact that the soils were formed from sediments deposited in past ages under the sea.

A high water table is a serious salinity hazard. Evaporation from surface soil or absorption of water by crop roots near the soil surface tends to produce a moisture gradient that causes water to move upward from the water table. Such movement of water carries additional salt into the upper layers of the soil and causes them to become more saline. The rate of salinization depends in part upon the salt concentration of the ground water, the depth to the water table, and the annual effective rainfall. The greater the concentration of salt in the ground water, the higher the water table, or the lower the annual effective rainfall, the faster the soil

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will become salinized. Effective rainfall is total rainfall minus the rainwater that runs off the soil surface or is lost through evapotranspiration.

The use of irrigation water containing too much salt, or poor management of even good irrigation water, can cause soils to become saline. All irrigation waters contain some salt. If the amount of water applied is not sufficient for a fairly large fraction of it to pass beyond the root zone, some of the salt contained in the irrigation water will remain in the root zone. The movement of some water and salt to a depth below the root zone requires larger applications of irrigation water than are necessary to support plant growth. This is particularly true on irrigated areas having very high evaporation rates or very low rainfall.

On some areas, including extensive rice-producing areas of India, soil salinity is caused by annual inundation with sea water.

The salinity status of a soil may be expressed in terms of the percent salt on a dry-soil basis or of the concentration of salt dissolved in the soil water. The latter value is preferred, because experimental evidence indicates that plant response is closely correlated with it. Usually the salt concentration in the soil solution is indicated in terms of parts per million or of the electrical conductivity of the soil solution. The electrical conductivity of a soil solution is readily determined from a saturated-soil extract and is referred to as the electrical conductivity of the saturation extract (EC_e). The procedure used in making this measurement is described in U.S. Department of Agriculture Handbook 60 (*15*).[3] In converting data from percent salt on a dry-soil basis to concentration of salt in the soil solution, it is necessary to take into consideration the moisture-holding characteristics of the soil. In other words, not only is it necessary to know the amount of salt in a unit volume of soil but it is also necessary to know the amount of water in which the salt is dissolved.

Reclamation of saline soil involves reducing soluble salt content to a level at which the salts will not seriously interfere with plant growth. The only practical way of removing salt from soil is washing it out with water, a process commonly referred to as leaching. To make sure that enough water will pass through a saline soil to wash out the excess salt, it is usually necessary to pond water on the surface (fig. 1).

Soils may become sodic through the use of irrigation waters that have an unfavorable ratio of sodium to calcium. Also, they may become sodic as a result of evaporation from high water tables in places where the ground water has such a ratio. Sodic soils may be reclaimed by adding a source of soluble calcium, which replaces the sodium on the soil particles. This is an exchange reaction, and the sodium and calcium are referred to as exchangeable sodium and exchangeable calcium. After being replaced by calcium, the sodium

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[3] Italic numbers in parentheses refer to Literature Cited, p. 13.

FIGURE 1.—Ponding water on the soil surface causes downward movement of salt with the water.

must be leached from the root zone. Thus the reclamation of a sodic soil, like that of a saline soil, involves a leaching operation.

Since a great majority of crop plants cannot survive prolonged submergence, crop production is usually impossible on salt-affected soil that is being leached. On a salt-affected area that is otherwise suitable for growing rice and for which irrigation water of low salt content is available, this crop can often be grown to provide some income while leaching is in progress.

MOVEMENT OF SALTS IN SUBMERGED SOILS

The water effective in leaching is the fraction of the applied water that actually passes through the root zone. This fraction, called the leaching water, is less than the total volume of the applied water because of evapotranspiration and runoff.

The results of a leaching experiment conducted on a saline soil in the Coachella Valley of California by Reeve et al. (*12*, *13*) indicated that after a unit depth of leaching water passed through an equal depth of soil only about 20 percent of the original quantity of salt remained in that depth of soil and only about 10 percent remained in its upper half (fig. 2). After 10 centimeters of leaching water passed through, for example, only 20 percent of the salt initially present in the surface 10 centimeters of soil remained and only 10 percent of that in the surface 5 centimeters remained.

The time required for reducing the salinity of a soil to the desired level by leaching varies according to the percolation rate, or the rate at which water will pass through the soil, and the quantity of water

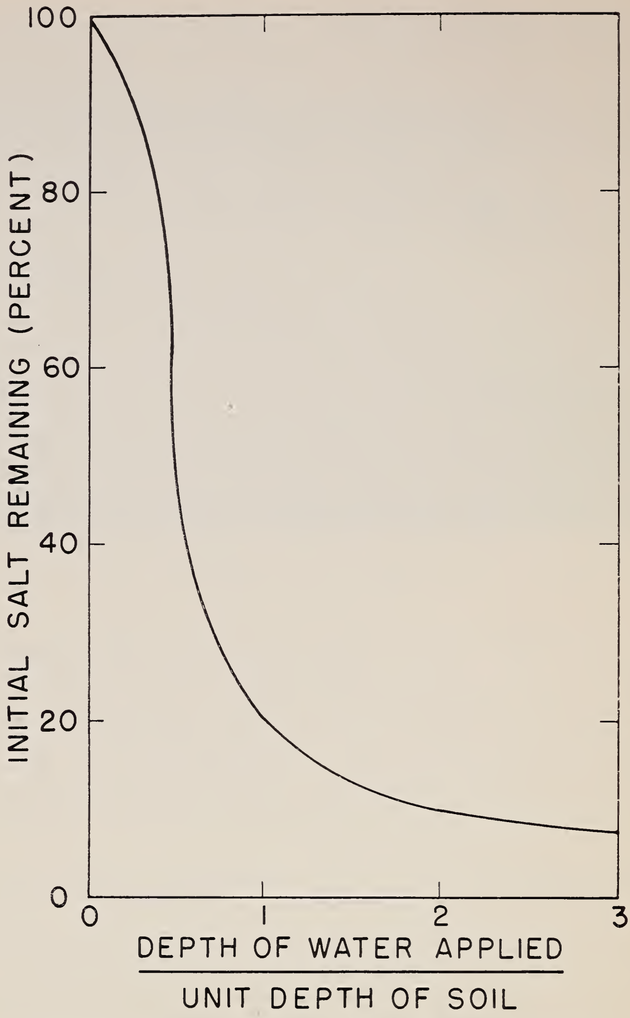

FIGURE 2.—Relation between the depth of leaching water applied to a saline soil and the percentages of the initial soluble salt content remaining in proportional depths of the soil. (Data from an experiment by Reeve et al. (*12*, *13*).)

required to remove the excess salts. A soil used in producing rice under submerged conditions usually has low permeability and a low percolation rate, either because of natural conditions or because of artificial puddling. This condition permits the production of rice with smaller quantities of water, but it also retards the rate of leaching.

An experiment was conducted at the U.S. Salinity Laboratory to determine the effect of initial soil salinity, irrigation-water salinity,

and percolation rate on final soil salinity and the growth of rice (*9*). The results indicated that the principal factors determining final soil salinity were the salt content of the irrigation water and the rate of percolation. Soluble salts initially present in the soil were moved downward and had relatively little effect on its final salinity status. The growth of rice was found to be related to the concentration of salt in the soil solution within the root zone.

Curves presented in figure 3 indicate (1) that the electrical conductivity of the soil solution is proportional to the electrical conduc-

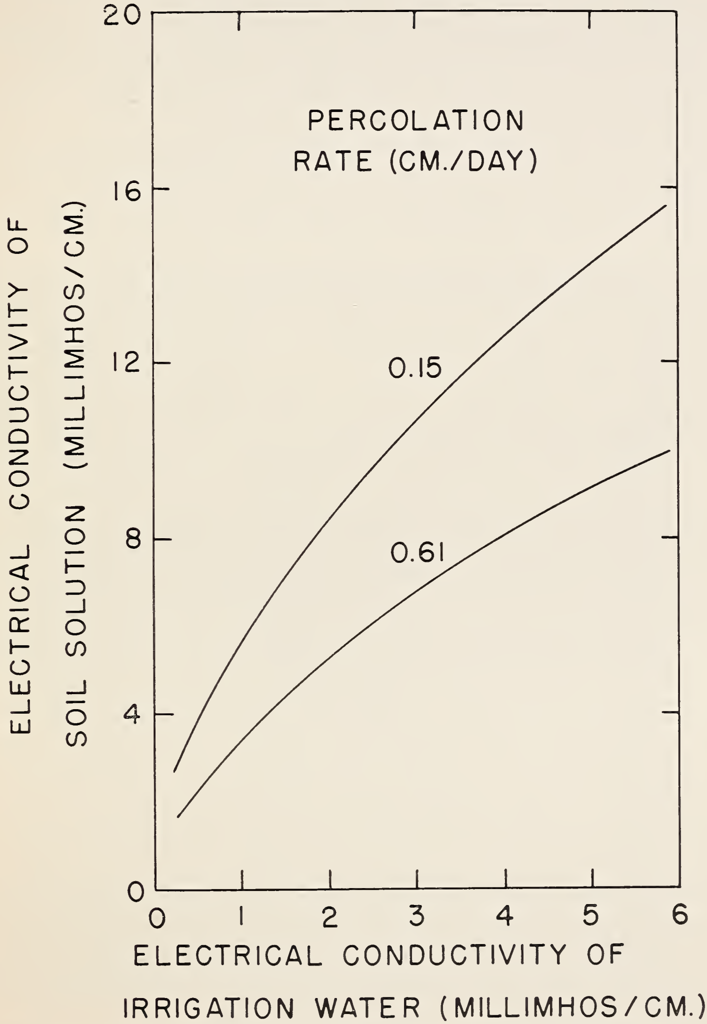

FIGURE 3.—Relation between the electrical conductivity of irrigation water applied and the conductivity of the soil solution, at percolation rates of 0.15 and 0.61 centimeter per day, in an experiment in which rice was grown in soil containers under greenhouse conditions (*9*).

tivity of the irrigation water applied; (2) that the conductivity of the soil solution associated with use of a given irrigation water is greater if the water percolates slowly; and (3) that the conductivity of the soil solution is greater in all cases than that of the irrigation water applied. The second and third of these relations are due to loss of water through evapotranspiration. Since the relationships indicated in figure 3 were influenced by the amount of evapotranspiration that occurred during the course of the experiment described, they do not necessarily represent those existing under other conditions.

Because the concentration of salt in irrigation water is sometimes expressed in parts per million, the general relationship between salt concentration thus expressed and electrical conductivity of surface waters is indicated in figure 4.

The electrical conductivity of irrigation water entering the soil at the surface is greater than that of the applied irrigation water, owing to the loss of water by evaporation. In turn, the electrical conductivity of the soil solution in the root zone is greater than that

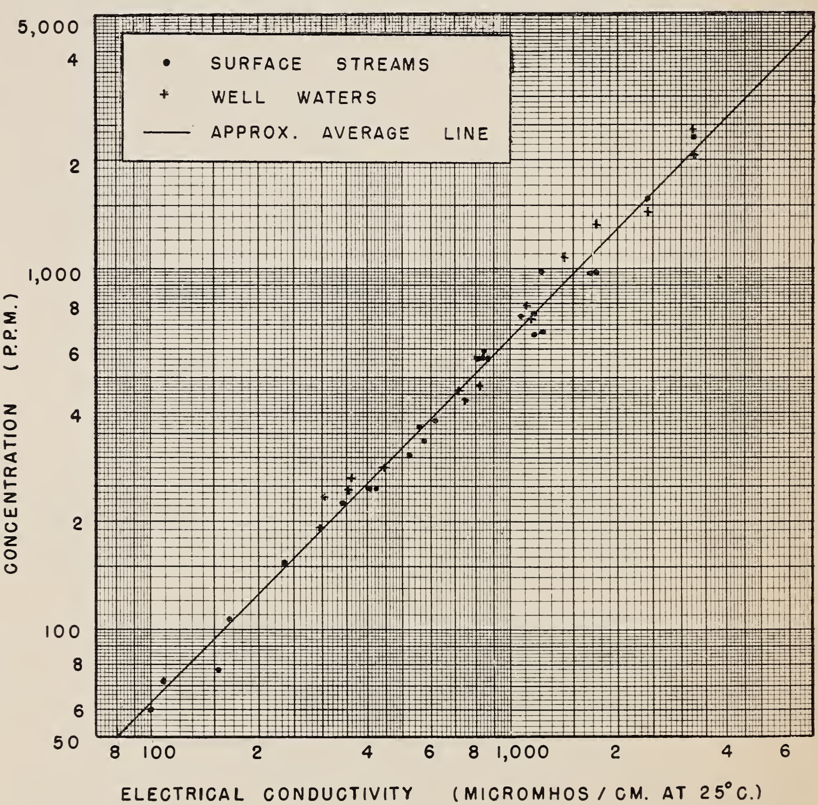

FIGURE 4.—Salt concentration of irrigation waters in parts per million as related to their electrical conductivity (*15*).

of the water entering at the surface of the soil, owing to the absorption and transpiration of water by plants. These evapotranspirational losses involve no removal of salts aside from the small amount absorbed by the plants. As the percolation rate decreases, these losses become relatively greater. This increases the difference between the electrical conductivity of the soil solution and that of the irrigation water.

The low percolation rates characteristic of soils used for producing rice mean that relatively small proportions of the irrigation waters applied pass through the root zone. The leaching requirement, that is, the fraction of the irrigation water that must pass through the root zone to prevent accumulation of excess soluble salts there, is dependent upon the salt content of the irrigation water applied and the level of salinity that can be tolerated in the soil solution. The percentage of an applied water having an electrical conductivity of from 0 to 6 millimhos per centimeter that must pass through the root zone of a soil to limit the conductivity of the soil solution to each of four levels is presented in figure 5.

Figure 5 shows that if, for example, it is desired to limit the electrical conductivity of the soil solution to 4 millimhos per centimeter in a soil in which only 20 percent of the water applied moves through the root zone, the conductivity of the applied water must not exceed 0.8 millimho; but that in a soil in which 50 percent of the irrigation water passes through the root zone, the same limit of soil salinity can be maintained when water having an electrical conductivity as great as 2 millimhos is being applied.

EFFECTS OF SALINITY ON GROWTH OF RICE

The osmotic pressure of a salt solution is proportional to the salt content of the solution. An increase in the osmotic pressure of a soil solution makes it more difficult for plant roots to absorb water to replace that lost by transpiration. Therefore the growth of plants, including rice, is retarded in saline soils.

Salinity causes a delay in germination and reduces the final percentage of germination (*1*, *2*). Unpublished data from sand-culture experiments conducted at the U.S. Salinity Laboratory indicate that a 50-percent reduction in the germination of rice within 10 days after planting was associated with an electrical conductivity of somewhat more than 20 millimhos per centimeter. (The reduction figures quoted here and later represent differences between germination or growth at the salinity values quoted and maximum germination or growth under comparable nonsaline conditions.) Among 12 individual rice varieties studied, only moderate differences were found in this regard. The results indicate that the salt tolerance of rice during germination is comparable to that of the more tolerant varieties of barley (*1*). Kapp (*6*) reported that applying 825 pounds of salt per acre to a nonsaline soil before planting rice reduced the

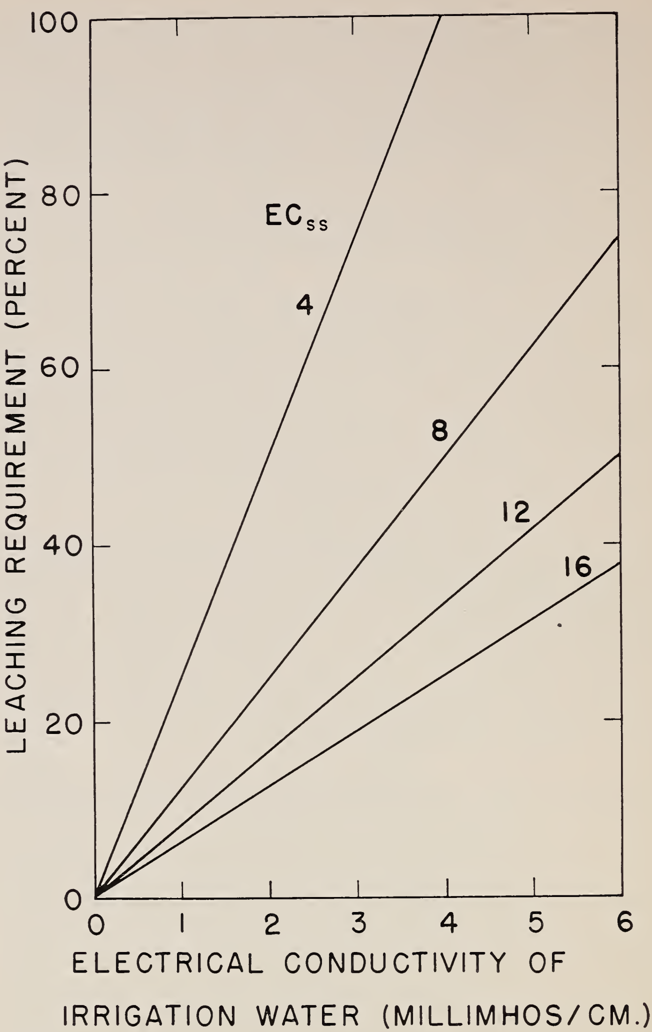

FIGURE 5.—Percentage of an irrigation water having an electrical conductivity of from 0 to 6 millimhos per centimeter that must pass through the root zone of a soil in order that the electrical conductivity of the soil solution (EC_{ss}) may be limited to 4, 8, 12, or 16 millimhos. (Data from an experiment by Reeve (*12*).)

grain yield by about 15 percent. He stated that this yield reduction appeared to be due mainly to reduction in germination and partly to loss of some of the young rice seedlings.

Although rice will germinate under highly saline conditions, the young seedlings are very sensitive to salt. When sprouted Caloro rice seed was planted in saline soil, the sprouts grew at soil-solution electrical conductivity values (millimhos per centimeter) up to

approximately 4, started to grow but died at values from 4 to 11, and failed to develop at values greater than 11 (*9*). Preliminary work on the salt tolerance of young rice seedlings has indicated that it may differ widely among varieties. For example, on the basis of number of plants surviving at 2 weeks of age, Kala-Rata (India) is more salt tolerant than either Agami Montakhab I (Egypt), Asahi #1 (Japan), or Caloro (U.S.).

In experiments of the Arkansas Agricultural Experiment Station, Kapp (*6*) reported, soil salinity existing at the time of planting did much more damage to rice than soil salinity of the same degree induced when the plants were 6 weeks old. Del Valle and Babé (*4*), studying the effect on rice of soil salinity induced 30, 60, and 90 days after planting, in Cuba, found that salinity did the most harm if induced at the earliest date. As the plants became older they tolerated progressively greater levels of salinity; at 90 days they were hardly affected by salt concentrations in the soil as great as 1 percent. Ota et al. (*7*) found that decrease in grain yield was proportional to the duration of the saline treatment. Studies at the U.S. Salinity Laboratory, also, have produced evidence that, beyond the early seedling stage, the salt tolerance of rice increases with age. Seedlings grown in nonsaline soil for 3 and for 6 weeks survived when transplanted in saline soils having electrical conductivity values up to 9 and 14 millimhos per centimeter, respectively (*9*). In another experiment at the Laboratory (*11*), in which several different salinity levels were induced in soil in which rice plants were growing and these levels were maintained until the plants matured, total dry weight of tops was related to the stages of development at which the salinity had been induced. Where an electrical conductivity of 3 millimhos per centimeter was maintained from the beginning of the tillering stage (4 weeks after seeding) to maturity, dry weight of tops was significantly less. Where conductivities of 4 and 8 millimhos per centimeter were maintained from the late tillering stage or the flowering stage (that is, from a time 9 weeks or 14 weeks after seeding) until maturity, weight was significantly less. The reduction in growth caused by a given salinity condition did not vary directly with the length of time the plants were grown under that condition.

It has been reported by Shimoyama and Ogō (*14*) and by Iwaki (*5*) that salinity caused an increase in the number of sterile florets per panicle of rice. Ota et al. (*8*) found that salinity caused a decrease in the percent germination of rice pollen grains, which resulted in a greater percentage of sterile florets. Salinity during the period of grain maturation in Iwaki's studies had little effect on grain yield (*5*).

With regard to grain production, preliminary experiments indicate that Agami Montakhab I (Egypt) is somewhat more salt tolerant than Asahi #1 (Japan), Caloro (U.S.), or Kala-Rata (India), and that the three varieties just named have about the same degree of tolerance.

In general, it may be said that rice is very tolerant of salt during germination but very sensitive to it during the early seedling stage, gains tolerance progressively during the tillering stage, again becomes sensitive when flowering, and is tolerant during the period of grain maturation; and that some rice varieties appear to be somewhat more salt tolerant than others. Extreme salinity makes it impossible to grow any variety of rice profitably.

The effect of salinity on growth of rice varies among different elements of growth—height, number of tillers, weight of grain, etc. (*5, 9*). Vegetative growth is less seriously affected than grain production. Salinity levels represented by electrical conductivity values averaging 11 millimhos per centimeter for the growing season as a whole reduced height by less than 20 percent, number of mature tillers by 45 percent, dry weight of straw by 55 percent, number of panicles by 70 percent, dry weight of grain plus straw by 75 percent, and weight of grain alone by 95 percent (*9*). The marked effect of salinity on grain yield is probably due to reduction in number of panicles and reduction in germination of pollen. A 50-percent reduction in the yield of Caloro grain was associated with an average electrical conductivity of 8 millimhos per centimeter for soil-solution samples extracted from the root zone throughout the growing season (*9*).

It is often difficult to recognize the existence of a salinity problem in a field of rice before the grain develops. This is in contrast with results obtained with barley (*3*). In the presence of salinity, whereas rice plants grow fairly tall but produce very little grain, barley plants make poor height growth but produce almost as much grain as under nonsaline conditions.

The relative salt tolerance of many crops has been determined and listed by the U.S. Salinity Laboratory (*15*) on the basis of the relation between yield and the electrical conductivity of the saturation extract (EC_e) in the root zone. A crop is classed as salt sensitive if its yield is reduced 50 percent by a seasonal-average level of salinity represented by an electrical conductivity (EC_e) value of 4 millimhos per centimeter. Since a soil contains about half as much moisture at field capacity as at saturation, the electrical conductivity of the soil solution is about twice as great in soil at field capacity as in saturated soil. Therefore, salt-sensitive crops ($EC_e=4$) normally grown at soil moisture contents equal to or less than field capacity can tolerate levels of salinity represented by electrical conductivity values of 8 millimhos or more per centimeter in the field moisture range. On this basis rice, which is normally grown in saturated soil, should be considered salt sensitive, because it can tolerate only 8 millimhos per centimeter in the saturation extract.

Rice has been found to be moderately tolerant of exchangeable sodium. A 50-percent decrease in the yield of Caloro rice grain was associated with an exchangeable-sodium-percentage (ESP) of 38 (*10*). In the absence of a serious salinity problem, it may be pos-

sible to grow rice during the reclamation of soils containing moderate proportions of exchangeable sodium, provided the leaching requirement can be satisfied.

CULTURE OF RICE IN CONNECTION WITH LEACHING

Because of the sensitivity of rice to salt during the early seedling stage, a field that is to be seeded with rice by drilling must have essentially nonsaline soil at the surface. If the seed is to be broadcast in water or immediately before flooding, slight salinity of the surface soil may be tolerated. In Asia, rice is sometimes grown in nonsaline soil in nursery beds and transplanted in saline field soil as 4- to 6-week-old seedlings, which can tolerate a somewhat higher salt content of the surface soil than younger seedlings. Areas to be used in growing rice for transplanting must be selected carefully with respect both to adequate drainage and to the absence of soil salinity. Highly saline soils in which rice is to be transplanted may require some preliminary leaching of the surface layer. For use under saline conditions, rice varieties that appear to be relatively salt tolerant should be selected.

Rice is a relatively shallow-rooted crop. Therefore, to establish a stand of rice, it is not necessary to move the salts to great depths. Continued leaching during the rice-growing season, affecting the soil to considerable depths, may make it possible to grow a deep-rooted crop after the rice has been harvested.

During the early part of the growing season, when rice is most sensitive to salt, irrigating of rice nursery beds and of saline surface soil on which rice is growing should, if possible, be done with rainwater or with water containing very little salt. In some areas, water from melting snow is available for this purpose. Later in the season the salt content of the water available for leaching is likely to increase, owing to reduction in volume of water in a river or to the necessity of supplementing river water with well water of higher salt content. However, the plants are then able to tolerate somewhat higher levels of salinity. In areas of high evaporation, frequent replenishment of the water on the soil surface may be necessary to offset the increase in salinity of the surface water that results from evaporation before the water enters the soil.

In order to grow crops in some areas that are potentially saline, it is necessary to leach salts from the root zone periodically. For this reason, rice is sometimes included in a crop rotation as a "leach crop." Such a program may make it possible to grow other crops profitably in alternating periods. The severity of the salinity problem determines the frequency with which rice must be included in the rotation. In some areas the soils may need continual leaching. In that case it will be impossible to grow any crop except the more salt-tolerant varieties of rice.

SUMMARY

Reclamation of salt-affected (saline, sodic, or saline-sodic) soils involves leaching excess salt out of the root zone, that is, washing it out with water. This usually necessitates ponding water on the surface. Rice, because it tolerates prolonged submergence, can often be grown with profit on soil that is undergoing leaching, if conditions are otherwise suitable for this crop and irrigation water of low salt content is available.

In general, rice is very tolerant of salt during germination but is very sensitive to it during the early seedling stage. It gains tolerance in the tillering stage and during maturation, but is sensitive at the time of flowering. Some varieties appear to tolerate salt better than others.

Soluble salts initially present in the root zone of a soil are moved downward by leaching water. Reduction of soil salinity in the root zone to a level that can be tolerated by plants depends principally on the passage of irrigation water through this zone in amounts sufficient to prevent accumulation of salt there. The final salinity status of soil subjected to leaching varies according to the salt content of the irrigation water and the rate of percolation. The time required for reducing soil salinity to a desired level by leaching varies according to the percolation rate and the quantity of water required.

A field that is to be seeded with rice by drilling must have essentially nonsaline soil at the surface. If the seed is to be broadcast in water or immediately before flooding, slight salinity of the surface soil may be tolerated. In Asia, rice is sometimes grown in nonsaline soil in nursery beds and transplanted in saline field soil as 4- to 6-week-old seedlings. Highly saline field soil may require some leaching at the surface before the transplanting.

Rice has a relatively shallow root system. Therefore, it is not necessary to move salts to any great depth in order to grow rice. Continued leaching throughout the rice-growing season, affecting the soil to considerable depths, may make it possible to grow a deep-rooted crop after the rice crop.

Growth of rice is retarded by soil salinity. The grain production is affected much more than the vegetative growth. Rice can produce half its normal grain yield only if the average electrical conductivity of the soil solution during the growing season is 8 millimhos or less per centimeter.

On potentially saline soil, rice is sometimes included in a crop rotation as a means of income during periodic leachings. Such a program may make it possible to grow other crops profitably in alternating periods. In some areas, soils may become saline so quickly that they need continual leaching. In this case it is impossible to grow any crop except the more salt-tolerant varieties of rice. Extreme salinity makes it impossible to grow any variety of rice profitably.

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